Renewable and Sustainable Energy Reviews 30 (2014) 290–298

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Electricity consumption from renewable and non-renewable sources and economic growth: Evidence from Latin American countries

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ARTICLE INFO

Article history:
Received 19 February 2013
Received in revised form
7 October 2013
Accepted 13 October 2013
Available online 8 November 2013

Keywords:
Renewable and non-renewable electricity consumption
Economic growth
Latin American countries
Panel data analysis

ABSTRACT

This study explores the effect of renewable and non-renewable electricity consumption on economic growth in 18 Latin American countries. To achieve the goal of this study a panel Gross Domestic Product (GDP) model was constructed taking the period 1980–2010 into account. From the Pedroni cointegration test results it was found that renewable electricity consumption, non-renewable electricity consumption, labor, gross fixed capital formation, and total trade are cointegrated. Moreover, the panel Dynamic Ordinary Least Squares (DOLS) test results revealed that all above the mentioned variables have a long run positive effect on GDP growth in the investigated countries. The Vector Error-Correction (VEC) Granger causality model results revealed the existence of feedback causality between the variables. The results of the study indicated that renewable electricity consumption is more significant than non-renewable electricity consumption in promoting economic growth in the investigated countries in the long run and the short run. Based on the results of this study, it is recommended that the investigated countries should increase their investment on renewable energy projects to increase the role of electricity consumption from renewable sources. In addition, it is essential that these countries should reduce their non-renewable electricity consumption by increasing their energy efficiency and implementing energy saving projects. By applying these recommendations, these countries would be able to mitigate global warming and reduce their dependency on fossil fuel to increase their energy security.

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1. Introduction

The economic growth in Latin American countries has been increasing substantially in the last three decades which resulted in intensifying their demand on electricity. During the period 1980–2010 electricity consumption increased more than 73%, this phenomenon encouraged the governments of these countries to increase their investment in power generation to meet their continuously expanding need of electricity. It is fundamental to note that Latin America is an active region in hydropower development. Moreover, there are several projects that were constructed to increase the power capacity of other renewable resources. However these projects are relatively small compared to the projects that have been conducted in other regions [1]. As mentioned above, Latin America is a leading region in hydroelectric power whereby most of its electricity production comes

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http://dx.doi.org/10.1016/j.rser.2013.10.006

from hydroelectric sources. These sources represent 52% of the total electricity production, while 39% of the total electricity production comes from fossil fuels and 10% comes from other renewable sources [2]. The large percentage of renewable energy (hydroelectricity, solar and wind) in the total production of electricity and the lack of studies that explore electricity–GDP relationship in Latin American countries motivated this study to examine the impact of electricity consumption from renewable and non-renewable sources on economic growth in 18 Latin American countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Panama, Paraguay, Peru, Uruguay and Venezuela. Fig. 1 below reviews the trend of real GDP, renewable electricity from hydro sources (ELH) and other renewable (ELR) sources, and non-renewable electricity consumption (ELF).These variables are progressing together in a positive trend in the last three decades. Based on the World Development Indicators (WDI), the Latin American region had witnessed a substantial increase in economic growth and electricity consumption from both renewable and non-renewable sources. The gross domestic product, electricity consumption from renewable sources, and electricity consumption from nonrenewable sources increased more than 60%, 70%, and 50% respectively.

The following section (Section 2) will review the literature that explored the relationship between electricity consumption and GDP growth. In addition, Section 3 will reveal the empirical model, data source and the panel methodology tests that will be utilized in the analysis. The empirical results and conclusion and discussion will be reviewed in Sections 4 and 5 respectively.

2. Literature review

Due to the importance of electricity in promoting economic growth and development, the electricity–GDP relationship was investigated by many researchers over the last decade. In Hong Kong [3], India [4,5], Portugal [6], Taiwan [7] and Malaysia [8], it was found that electricity consumption and economic growth are cointegrated, furthermore, a one way causal relationship from economic growth to electricity was found. Similarly, causal relationship between electricity consumption and economic growth was found in Bangladesh [9] and Cote d'Ivoire [10]. However, a bi-directional causal relationship between electricity consumption and economic growth was found in Malawi [11] and Poland [12]. A cointegration relationship between electricity consumption and economic growth and a one way causal relationship from electricity consumption to economic growth was also found in former Soviet Republics by Bildirici and Kayıkçi [13], Nigeria by Akinlo [14], Lebanon by Abosedra et al. [15], China by Shiu and Lam [16], Bangladesh by Ahamad and Islam [17], Malaysia by Chandran et al. [18], Fiji Islands by Narayan and Singh [19], China by Shengfng et al. [20], and the Middle East by Narayan and Smyth [21]. The same results were also found in Turkey by Altinay and Karagol [22] and Pakistan by Jamil and Ahmad [23]. However, in Malaysia, Tang [24] found a bi-directional causal relationship, rather than cointegration, between electricity consumption and economic growth. Furthermore, electricity consumption and economic growth were found to be cointegrated and interrelated in a bi-directional causal relationship in South Korea [25]. Similar results were concluded by Ouédraogo [26] in Burkina Faso, in South Africa by Odhiambo [27], in Algeria by BélaÏd and Abderrahmani [28], in Malaysia by Tang and Tan [29], and in Pakistan by Shahbaz and Lean [30]. In addition, Narayan et al. [31] found that electricity consumption increased economic growth for all the seven major developed (G-7) countries except for the U.S, thus, electricity conservation policies will definitely result in harming the economic growth of the G-7 countries, excluding the U.S. The relationship between electricity consumption and economic growth varied between the African countries based on Wolde-Rufael [32], he found that electricity consumption and economic growth are cointegraed in a number of African countries. He also found that some African countries have a unidirectional causality from economic growth to electricity consumption while a bi-directional causality relationship between the variables was found in the rest of the African countries. In addition, Squalli [33] also found mixed results between the diverse Organization of the Petroleum Exporting Countries (OPEC). While some countries' economic growth is dependent on electricity, other countries are less dependent or independent on electricity in achieving their economic growth. Yoo and Kwak [34] found that the causal relationship between electricity consumption and economic growth varied across the South American countries whereby the causal relationship was unidirectional from electricity consumption to economic growth in Argentina, Brazil, Chile, Colombia and Ecuador. They also found that the causal relationship between electricity consumption and economic growth was bi-directional in Venezuela. Nonetheless, no causal relationship was found between the two variables in Peru. Likewise, Narayan and Prasad [35] found a mixed causal relationship between electricity consumption and economic growth in the Organization for Economic Co-operation and Development (OECD) countries whereby unidirectional causal relationship from electricity consumption to economic growth was found in a number of OECD countries while the rest of the countries have no causal relationship between them. Different causal relationships were reached in ASEAN countries by Yoo [36], who found a bi-directional causal relationship between electricity consumption and economic growth in Malaysia and Singapore while a unidirectional causal relationship from electricity consumption to economic growth was found in Indonesia and Thailand. In addition, Apergis and Payne [37] concluded that the relationship between electricity consumption and economic growth varied between the countries based on their level of income. The results of the study indicated that a bi-directional causality between electricity consumption and economic growth was found in high, upper and lower middle income countries, while a one way causal relationship was found in low income countries. Furthermore, they also emphasized that the long run relationship between the variables is present in all income level countries. However, Ozturk and Acaravci concluded that there is neither long run relationship nor short run relationship between electricity consumption and economic growth in a number of Middle East and North Africa (MENA) countries [38] and in transition countries [39].

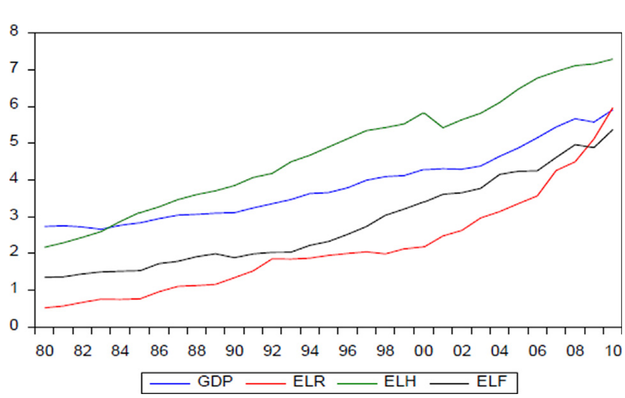


Fig. 1. Trend in GDP growth, electricity consumption from renewable sources and electricity consumption from non-renewable sources 1980–2010. (World Development Indicators (WDI) 2013).

The relationship between electricity consumption from renewable sources and economic growth was examined by few studies.

Table 1
Summary of the studies that examined the GDP Growth–Electricity Consumption Relationship.

Author	Time period	Country	Methodology	Results
Ho and Siu [3]	1966–2002	Hong Kong	Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. Electricity consumption → GDP growth.
Ghosh [4]	1950–1997	India	Johansen cointegration test VAR Granger causality	Electricity and GDP growth are not cointegrated. GDP growth → electricity consumption.
Abbas and Choudhury [5]	1972–2008	Pakistan & India	Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. Electricity consumption → GDP growth in Pakistan. Electricity consumption ↔ GDP growth in India.
Shahbaz et al. [6]	1971–2009	Portugal	ARDL bound testing Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated and have a long run relationship. Electricity consumption ↔ GDP growth in India.
Pao [7]	1980–2007	Taiwan	Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. GDP growth → electricity consumption.
Lean and Smyth [8]	1970–2008	Malaysia	ARDL bound testing Toda–Yamamoto Granger causality.	Electricity and GDP growth are cointegrated. GDP growth → electricity consumption.
Mozumder and Marathe [9]	1971–1999	Bangladesh	Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. GDP growth → electricity consumption.
Kouakou [10]	1971–2008	Cote d'Ivoire	ARDL bound testing VECM Granger causality	Electricity and GDP growth are cointegrated. Electricity consumption ↔ GDP growth.
Jumbe [11]	1970–1999	Malawi	ADF cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. Electricity consumption ↔ GDP growth.
Gurgul and Lach [12]		Poland	Johansen cointegration test Toda–Yamamoto Granger causality.	Electricity and GDP growth are cointegrated. GDP growth → electricity consumption.
Bildirici and Kayıkçı [13]	1990–2009	Soviet Republics	Pedroni cointegration test Fully modified OLS test ARDL bound testing VECM Granger causality	Electricity and GDP growth are cointegrated. Electricity consumption → GDP growth.
Akinlo [14]	1980–2006	Nigeria	Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. Electricity consumption → GDP growth.
Abosedra et al. [15]	1995–2005	Lebanon	VAR Granger causality	Electricity consumption → GDP growth.
Shiu and Lam [16]	1971–2000	China	Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. Electricity consumption → GDP growth.
Ahamad and Islam [17]	1971–2008	Bangladesh	Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. Electricity consumption ↔ GDP growth.
Chandran et al. [18]	1971–2003	Malaysia	ARDL bound testing VECM Granger causality	Electricity and GDP growth are cointegrated. Electricity consumption → GDP growth.
Narayan and Singh [19]	1971–2002	Fiji	ARDL bound testing, Fully modified OLS (FMOLS) and OLS. VECM Granger causality	Electricity and GDP growth are cointegrated and electricity has a long run positive effect on GDP growth Electricity consumption → GDP growth.
Shengfeng et al. [20]	1953–2009	China	Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. Electricity consumption → GDP growth.
Narayan and Smyth [21]	1974–2002	Middle East	Westerlund panel cointegration VECM Granger causality	Electricity and GDP growth are cointegrated and electricity has a long run positive effect on GDP growth. Electricity consumption ↔ GDP growth.
Altinay and Karagol [22]	1950–2000	Turkey	the Dolado–Lütkepohl test and the standard Granger causality test	Electricity consumption → GDP growth.
Jamil and Ahmad [23]	1960–2008	Pakistan	Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. GDP growth → energy consumption.
Tang [24]	1972–2003	Malaysia	ARDL bound testing VECM and MWALD Granger causality	Electricity and GDP growth are cointegrated. GDP growth ↔ energy consumption.
Yoo [25]	1970–2002	South Korea	Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. GDP growth ↔ energy consumption.
Ouédraogo [26]	1968–2003	Burkina Faso	ARDL bound testing VECM Granger causality	Electricity and GDP growth are cointegrated. GDP growth ↔ energy consumption.
Odhiambo [27]	1971–2006	South Africa	Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated. GDP growth ↔ energy consumption.
BélaÏd and Abderrahmanl [28]	1971–2010	Algeria	Zivot–Andrews test; Gregory–Hansen cointegration test. VECM Granger causality.	Electricity and GDP growth are cointegrated. GDP growth ↔ energy consumption.
Tang and Tan [29]	1970–2009	Malaysia	ARDL bound testing. VECM Granger causality	Electricity and GDP growth are cointegrated. GDP growth ↔ energy consumption.
Shahbaz and Lean [30]	1972–2009	Pakistan	ARDL bound testing. Johansen cointegration test VECM Granger causality	Electricity and GDP growth are cointegrated and electricity has a long run positive effect on GDP growth. Electricity consumption ↔ GDP growth.
Narayan et al. [31]	1970–2002	G-7 countries	Impulse response function	Electricity consumption positively response to GDP growth and vice versa
Wolde-Rufael [32]	1971–2001	African countries	ARDL bound testing. Toda–Yamamoto Granger causality.	Electricity and GDP growth are cointegrated in Benin, Cameroon, Morocco and Zambia but not in Congo Republic, Gabon, Nigeria, South Africa and Zimbabwe. GDP growth → energy consumption in 6 of the countries. Electricity consumption → GDP growth in 3 countries. Electricity consumption ↔ GDP growth in 3 countries.
Squalli [33]	1980–2003	OPEC	ARDL bound testing.	Electricity and GDP growth are cointegrated.

Table 1 (*continued*)

Author	Time period	Country	Methodology	Results
			Toda–Yamamoto Granger causality.	Electricity consumption → GDP growth in Indonesia, Nigeria, UAE and Venezuela. GDP growth → electricity consumption in Algeria, Iraq, Kuwait and Libya. Electricity consumption ↔ GDP growth in Iran, Qatar and Saudi Arabia.
Yoo and Kwak [34]	1975–2006	Seven South American countries	Johansen cointegration test	Electricity and GDP growth are cointegrated only in Brazil, Columbia, Ecuador and Venezuela.
			Hsiao Granger causality tests	Electricity consumption → GDP growth in Argentina, Brazil, Chile, Columbia, and Ecuador.
			VECM Granger causality	Electricity consumption ↔ GDP growth in Venezuela. Electricity consumption ≠ GDP growth in Peru.
Narayan and Prasad [35]	1971–2002	OECD countries	Bootstrap Granger causality	Electricity consumption → GDP growth in Australia, Iceland, Italy, the Slovak Republic, the Czech Republic, Korea, Portugal, and the UK. Electricity consumption ≠ GDP growth in the rest of the 22 OECD countries.
Yoo [36]	1971–2002	ASEAN	Engle–Granger cointegration tests Hsiao Granger causality tests	Electricity and GDP growth are not cointegrated. GDP growth ↔ energy consumption in Malaysia and Singapore. GDP growth → energy consumption in Indonesia and Thailand
Apergis and Payne [37]	1990–2006	88 countries	Larsson et al. [51] panel cointegration test.	Electricity and GDP growth are cointegrated.
			VECM Granger causality	GDP growth ↔ energy consumption in high, upper middle and lower middle income countries. Electricity consumption → GDP growth in low income countries.
Ozturk and Acaravci [38]	1971–2006	11 MENA countries	ARDL bound testing	Electricity and GDP growth are cointegrated only for few countries.
			VECM Granger causality	GDP growth → energy consumption in Israel and Oman. Electricity consumption → GDP growth in Egypt and Saudi Arabia.
Ozturk and Acaravci [39]	1990–2006	Transition countries	Pedroni cointegration. VECM Granger causality	Electricity and GDP growth are no cointegrated Electricity consumption ≠ GDP growth
Fang [40]	1978–2008	China	Multivariate OLS test	The increase in renewable electricity consumption will increase GDP.
Apergis and Payne [41]	1990–2007	Emerging countries	Pedroni cointegration. FMOLS	Renewable and non-renewable electricity and GDP growth are cointegrated and renewable and non-renewable electricity have a long run effect on GDP growth.
			VECM Granger causality	Electricity consumption ↔ GDP growth.
Apergis and Payne [42]	1990–2007	80 countries	Pedroni cointegration. FMOLS	Renewable and non-renewable electricity and GDP growth are cointegrated and renewable and non-renewable electricity have a long run effect on GDP growth.
			VECM Granger causality	Electricity consumption ↔ GDP growth.
Apergis and Payne [43]	1992–2007	Eurasia	Pedroni cointegration.	Renewable and non-renewable electricity and GDP growth are cointegrated and renewable electricity have a long run effect on GDP growth.
			FMOLS VECM Granger causality	Electricity consumption ↔ GDP growth.
Apergis and Payne [44]	1985–2005	OECD countries	Pedroni cointegration.	Renewable and non-renewable electricity and GDP growth are cointegrated and renewable electricity have a long run effect on GDP growth.
			FMOLS VECM Granger causality	Electricity consumption ↔ GDP growth.
Apergis and Payne [45]	1980–2006	Central America	Pedroni cointegration. FMOLS	Renewable and non-renewable electricity and GDP growth are cointegrated and renewable electricity have a long run effect on GDP growth.
			VECM Granger causality	Electricity consumption ↔ GDP growth.
Sadorsky [46]	1994–2003	Emerging countries	Pedroni cointegration.	Renewable and non-renewable electricity and GDP growth are cointegrated and renewable electricity have a long run effect on GDP growth.
			FMOLS, DOLS and OLS VECM Granger causality	Electricity consumption ≠ GDP growth.

Note: ↔ indicates a b-directional causal relationship, → indicates a one way causal relationship, ≠ indicates no causal relationship, ELC is the total electricity consumption and GDP is the gross domestic product.

In China, Fang [40] concluded that the increase of renewable electricity consumption will result in increasing the country's economic growth and the level of income. In addition, Apergis and Payne found that renewable energy has a long run effect on economic growth and bi-directional causal relationship between the variables in emerging economies [41], in a number of developed and developing countries [42], in Eurasia [43], in OECD countries [44], and in Central America [45]. Furthermore, Sardorsky [46] found that the increase of economic growth in the emerging economies results in intensifying their consumption of renewable electricity. Table 1 below reviews a summary of the previous studies that explored the electricity consumption and GDP growth.

Despite the large literature that explored the relationship between electricity consumption and economic growth, the studies' results were mixed. From the above literature this study finds a number of gaps:

1. There is a lack of studies that explored the relationship between electricity consumption (renewable and non-renewable sources) and economic growth in the Latin American countries despite their substantial increase in their electricity consumption.
2. Most of the studies used total electricity consumption without disaggregating it in to renewable and non-renewable energy. Disaggregating electricity to renewable and nonrenewable sources can show the effect of each electricity source on Latin America's economic growth which can provide more policy implications. Consequently, this study will explore the electricity consumption (renewable and non-renewable) and economic growth relationship in the Latin American countries. Moreover, this study will use in its investigation all the renewable sources of electricity including the hydropower which accounted for more than 50% from the total electricity consumption of their total electricity production in 2010 (World Development Indicators).

3. Econometric procedure and data

This study used the panel data methodology due to its numerous advantages such as controlling the heterogeneity and the colinearity between the variables, increasing the degree of freedom, and its well known reliablity compared to the normal time series methodologies [47]. The panel economic growth model is specified as follows:

$$\mathrm{LGDP}_{it} = \beta_{0i} + \beta_{1i}\mathrm{LRE}_{it} + \beta_{2i}\mathrm{LNRE}_{it} + \beta_{3i}\mathrm{LL}_{it} + \beta_{4i}\mathrm{LGFC}_{it} + \beta_{5i}\mathrm{LTD}_{it} + u_{it} \quad (1)$$

LGDP is the log of gross domestic product measured in millions of 2000 constant US dollars. LRE is the log of electricity consumption from renewable sources measured in million kilowatt-hours, including hydroelectricity. LNRE is the electricity consumption from oil, gas and coal sources measured in million kilowatt-hours. In addition, three control variables are added to the model namely, LL which is total labor force measured in thousands of workers, LGFC is the log of gross fixed capital formation measured in millions of 2000 constant US dollar, and LTD is the log of total trade of goods and services measured in millions of 2000 constant US dollar. i denotes the 1…18 Latin America countries under investigation, t is the time period from 1990 to 2010, and u is the error term. Annual data used in this study are taken from the period 1980–2010. Furthermore, all the variables are retrieved from the World Development Indicators (WDI).

The first step in the analysis was to test the stationarity of the variables. This is achieved by utilizing the panel unit root test. The panel unit root test had become popular among researchers due to its higher power compared to the individual time series. Theoretically, the panel unit root tests are simply multiple-series unit root test modified for panel structures. Two types of panel unit root tests are utilized namely, the Levin, Lin, and Chu (LLC) and the Im, Pesaran, and Shin (IPS). The LLC unit root test assumes that there is a common unit root so that the pi is the same across the cross section while the IPS unit root test allows an individual unit root process so that pi can vary across the cross sections. The null hypothesis is based on the notion that there is a unit root, while the alternative hypothesis is based on the idea that there is no unit root. Both LLC and IPS tests work under the basis of the Augmented Dickey–Fuller (ADF) test as in the following equation:

$$\Delta y_{it} = \alpha y_{it-1} + \sum_{j=1}^{pi} \beta_{ij} \Delta y_{it-j} + X'_{it}\delta + \epsilon_{it} \quad (2)$$

where we believe a common $\alpha = p-1$, but allow the lag order for different terms to vary across the section.

The Pedroni cointegration [48,49] test is utilized by a number of studies such as Bildirici and Kayıkçı [13], Ozturk and Acaravci [39], Apergis and Payne [41–45] and Sadorsky [46]. This test is implemented only when the variables are dubbed stationary at the first difference. The Pedroni cointegration is fundamental in examining whether the variables are cointegrated or not. Moreover, it allows for heterogeneous intercepts and trend coefficients across countries which are presented in the following equation:

$$y_{it} = \alpha_i + \delta_i t + \beta_{1i} x_{1i,t} + \beta_{2i} x_{2i,t} + \ldots + \beta_{Mi} x_{Mi,t} + e_{i,t} \quad (3)$$

y and x are assumed to be integrated in order one. The parameters α_i and δ_i are individual and trend effects, respectively, which may be zero if preferred. The residual e_{it} is integrated in order one under the null hypothesis of no cointegration. The null hypothesis of the Pedroni cointegration is that there is no cointegration. Rejecting the null hypothesis of no cointegration is based on several statistics namely, the homogenous alternative (within-dimension test or panel statistics test) and the heterogeneous alternative which is also referred to as the between-dimension.

If the variables are cointegrated, the Panel Dynamic Ordinary Least Squares (DOLS) is utilized to explore whether LGDP, LUR, LFD and LTD have a positive or a negative long run relationship with LEC. This method was used previously by Sadorsky [46] and the panel DOLS was proposed by Pedroni [50]. The DOLS method involves expanding the cointegration regression with lags and leads of ΔX_{it} so that the resulting cointegration equation error term is orthogonal to the entire history of the stochastic regressor innovations:

$$y_{it} = X'_{it}\beta + D'_{1it} y_i + \sum_{j=-q}^{r} \Delta X_{it+j}\delta + v_{1it} \quad (4)$$

It is crucial to note that adding q lags and r leads of the different regressors eliminate all the long run correlation between the residuals.

The Granger causality test is used to examine the bi-directional causal relationship between the variables. When the Pedroni cointegration test results reveal that the variables are cointegrated, the Granger causality, based on the Vector Error-Correction Model (VECM), can be applied. The VECM Granger causality have the capacity to capture the short run causality based on the F-statistics and the long run causality based on the lagged error correction model ect(-1). The VECM Granger causality model can be specified as follows:

$$\begin{bmatrix} \Delta\mathrm{LGDP}_{it} \\ \Delta\mathrm{LRE}_{it} \\ \Delta\mathrm{LNRE}_{it} \\ \Delta\mathrm{LL}_{it} \\ \Delta\mathrm{LGFC}_{it} \\ \Delta\mathrm{LTD}_{it} \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \end{bmatrix} + \Sigma_{p-1}^{r} \begin{bmatrix} \beta_{11p} & \beta_{12p} & \beta_{13p} & \beta_{14p} & \beta_{15p} & \beta_{16p} \\ \beta_{23} & \beta_{24p} & \beta_{25p} & \beta_{26p} & \beta_{27p} & \beta_{28p} \\ \beta_{35} & \beta_{36p} & \beta_{37p} & \beta_{38p} & \beta_{39p} & \beta_{40p} \\ \beta_{47p} & \beta_{48p} & \beta_{49p} & \beta_{50p} & \beta_{51p} & \beta_{52p} \\ \beta_{59p} & \beta_{60p} & \beta_{61p} & \beta_{62p} & \beta_{63p} & \beta_{64p} \\ \beta_{71p} & \beta_{72p} & \beta_{73p} & \beta_{74p} & \beta_{75p} & \beta_{76p} \end{bmatrix}$$

$$\times \begin{bmatrix} \Delta\mathrm{LGDP}_{it} \\ \Delta\mathrm{LRE}_{it} \\ \Delta\mathrm{LNRE}_{it} \\ \Delta\mathrm{LL}_{it} \\ \Delta\mathrm{LGFC}_{it} \\ \Delta\mathrm{LTD}_{it} \end{bmatrix} + \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \varphi_4 \\ \varphi_5 \\ \varphi_6 \end{bmatrix} \mathrm{ect}_{it-1} + \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \\ \varepsilon_{4it} \\ \varepsilon_{5it} \\ \varepsilon_{6it} \end{bmatrix} \quad (5)$$

where t denotes the time (1980–2010), i denotes the cross section (1…18 Latin America countries), ε_{it} is the error term, and ect is the lagged error correction term. On the other hand, when the variables are not cointegrated, the Granger causality based on the Vector Autoregression (VAR) model, which capture the short run causality only, is applied. The VAR Granger causality model can be specified

as follows:

$$\begin{bmatrix} \Delta LGDP_{it} \\ \Delta LRE_{it} \\ \Delta LNRE_{it} \\ \Delta LL_{it} \\ \Delta LGFC_{it} \\ \Delta LTD_{it} \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \end{bmatrix} + \sum_{p-1}^{r} \begin{bmatrix} \beta_{11p} & \beta_{12p} & \beta_{13p} & \beta_{14p} & \beta_{15p} & \beta_{16p} \\ \beta_{23} & \beta_{24p} & \beta_{25p} & \beta_{26p} & \beta_{27p} & \beta_{28p} \\ \beta_{35} & \beta_{36p} & \beta_{37p} & \beta_{38p} & \beta_{39p} & \beta_{40p} \\ \beta_{47p} & \beta_{48p} & \beta_{49p} & \beta_{50p} & \beta_{51p} & \beta_{52p} \\ \beta_{59p} & \beta_{60p} & \beta_{61p} & \beta_{62p} & \beta_{63p} & \beta_{64p} \\ \beta_{71p} & \beta_{72p} & \beta_{73p} & \beta_{74p} & \beta_{75p} & \beta_{76p} \end{bmatrix} \times \begin{bmatrix} \Delta LGDP_{it} \\ \Delta LRE_{it} \\ \Delta LNRE_{it} \\ \Delta LL_{it} \\ \Delta LGFC_{it} \\ \Delta LTD_{it} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \\ \varepsilon_{4it} \\ \varepsilon_{5it} \\ \varepsilon_{6it} \end{bmatrix} \quad (6)$$

4. Empirical results

In the first step of the analysis, the Levin, Lin & Chu and Im, Pesaran and Shin panel unit root tests were applied. Table 2 reviews the panel unit root test results which show that all the variables are not significant at the levels. Thus, the null hypothesis, whereby the variables contain a panel unit root, cannot be rejected. This, it turn, indicates that the variables are not stationary. However, all the variables were significant at the first difference. Hence, the variables are stationary at the first difference which results in rejecting the null hypothesis.

The Pedroni cointegration is utilized subsequently after recognizing that the variables are stationary at the first difference. The Pedroni cointegration test is essential in examining whether the LRE, LNRE, LL, GFC and LTD are cointegrated with LGDP. Table 3 reviews the results of the Pedroni cointegration test. The results reveal that six statistics were significant, hence, rejecting the null hypothesis of cointegration. The results also confirm the existence of a long run relationship between the independent variables namely LRE, LNRE, LL, GFC, LTD, and the dependent variable LGDP.

Table 2
Panel unit root test results.

Variables	*Level*		*First difference*	
	Intercept	*Intercept and trend*	*Intercept*	*Intercept and trend*
Panel I: Levin, Lin & Chu				
LGDP	4.22583	1.66248	−4.51079***	−2.27379**
LRE	−0.84038	−0.76654	−10.7021***	−9.22055***
LNRE	−0.95238	7.32285	−9.29545***	−7.59191***
LL	3.00327	5.79899	−3.86571***	−3.18873***
LGFC	0.14006	1.35326	−2.17391**	−9.19307***
LTD	−1.16962	0.90840	−6.82189***	−6.80935***
Panel II: Im, Pesaran and Shin				
LGDP	0.00622	0.57874	−5.06398***	−4.78651***
LRE	1.37535	0.584372	−10.5797***	−8.69637***
LNRE	0.02363	0.49716	−10.1124***	−6.70567***
LL	6.13713	1.25792	−4.49193***	−2.34234***
LGFC	1.83833	0.11047	−9.33724***	−9.27242***
LTD	3.67387	2.03906	−6.03931***	−4.32120***

Note: The unit root tests were done with individual trends and intercept for each variable, the optimal lag length were selected automatically using the Schwarz Information Criteria (SIC).

*** Significance at 1%.

** Significance at 5%.

Table 3
Pedroni cointegration test results.

Tests	**Statistics**	***p*-Values**
Panel *v*-statistic	−0.850401	0.8024
Panel *ρ*-statistic	3.614135	0.9998
Panel PP-statistic	−1.652381**	0.0492
Panel ADF-statistic	−2.549609***	0.0054
Panel *v*-statistic (Weighted Statistic)	−1.523885	0.9362
Panel *ρ*-statistic (Weighted Statistic)	3.783759	0.9999
Panel PP-statistic (Weighted Statistic)	−1.535220*	0.0624
Panel ADF-statistic (Weighted Statistic)	−2.238624**	0.0126
Group *ρ*-Statistic	5.433272	1.0000
Group PP-statistic	−2.906770***	0.0018
Group ADF-statistic	−2.442190***	0.0073

Lag length and bandwidth are selected by Schwarz Information Criterion (SIC) and the Bartlett kernel Newey–West estimator.

* Significance at 10% level.

** Significance at 5% level.

*** Significance at 1% level.

Since the variables are cointegrated, the next goal in the analysis is to examine whether LRE, LNRE, LL, GFC and LTD have a negative or positive long run relationship on the LGDP. This goal can be reached by utilizing the panel dynamic OLS (DOLS). Table 4, below, reviews the dynamic OLS test results. At the country level, this study found different results among the countries. 11 out of the 18 countries show that non-renewable electricity consumption has a positive long run effect on the economic growth. On the other hand, 14 out of the 18 countries show that renewable energy electricity consumption has a positive long run effect on their economic growth. Moreover, the higher the significance of renewable electricity consumption , the higher the share of renewable electricity of total electricity consumption. In addition, most of the Latin American countries show that gross fixed capital formation, labor and total trade have a positive long run effect on economic growth. Despite the mix results among the countries, the policy implication is based on the panel results, since this study is utilizing the panel data methodology. The panel results reveal that nonrenewable electricity consumption, renewable electricity consumption, gross fixed capital formation, total labor, and total trade have a positive long run effect on the economic growth in Latin America. One percent increase in renewable electricity consumption will increase economic growth by 0.370619% while an increase in non-renewable electricity consumption by 1% will increase economic growth by 0.4222878%. In addition, the increase in gross fixed capital formation, total labor force and total trade will increase economic growth by 0.496302%, 1.839365% and 0.3610855% respectively. The most important finding in this test is that the renewable electricity consumption plays a more significant effect in increasing economic growth than the non-renewable electricity consumption in the investigated countries.

The Granger causality based on the Vector Error-Correction Model (VECM) can be utilized after discovering cointegration. The Granger causality is important in the analysis because it can reveal the causal relationship between the variables. Table 5, below, reviews the Granger causality tests results. The results reveal the existence of a bi-directional causal relationship between renewable electricity consumption and economic growth, total trade and economic growth, renewable electricity consumption and non-renewable energy consumption, and total labor force and gross fixed capital formation. In addition, a one way causal relationship was found from non-renewable energy consumption to economic growth, gross fixed capital formation to economic growth, total labor force to renewable electricity consumption, total trade to renewable electricity consumption, gross fixed capital formation to non-renewable electricity consumption, and total labor force to

Table 4
The results of Panel group mean DOLS.

Country	Dependent variable: LGDP				
	LRE	LNRE	LGFC	LL	LTD
Argentina	0.316701*** (2.997078)	0.623697*** (5.696026)	0.711046*** (9.352730)	2.681119*** (5.827797)	0.071900*** (5.556581)
Bolivia	0.385382*** (3.257930)	0.081893 (0.081893)	0.283540*** (4.946795)	0.502849 (0.511851)	0.365374*** (6.293548)
Brazil	0.772395** (2.432584)	0.014855 (0.220522)	0.847625*** (7.196873)	0.740602 (0.776840)	−0.106434 (−0.587568)
Chile	0.316304* (2.053582)	0.208684** (2.350029)	0.265383** (3.013134)	2.406733** (2.328874)	0.451961*** (6.093594)
Colombia	0.008304 (0.175606)	0.370890*** (3.341073)	0.060360 (1.195809)	0.505309 (1.646800)	0.962122*** (11.99530)
Costa Rica	0.035820** (2.262199)	0.317023*** (5.273390)	0.482343*** (4.796264)	1.320381** (2.854362)	0.281687*** (3.253607)
Cuba	0.289938*** (3.981232)	0.181156** (2.568441)	0.125421 (1.107875)	1.663904*** (9.461731)	0.545650*** (5.031715)
Dominican Republic	0.213017** (2.482719)	0.168796 (0.943058)	0.727292** (2.742081)	0.104079 (0.254993)	0.128668 (0.222717)
Ecuador	0.351506*** (4.459340)	0.339487** (2.295636)	0.842078*** (5.141461)	0.180461 (0.568409)	0.106504 (0.583633)
El Salvador	0.146106** (2.547108)	0.061471 (1.319473)	0.119097 (1.132986)	0.336133** (2.922282)	0.691666*** (10.15316)
Guatemala	0.144639 (0.781662)	0.016936 (0.212472)	0.798235*** (3.302714)	2.286741*** (3.612496)	0.533943* (2.040546)
Honduras	0.254373* (2.059126)	0.052402 (1.573994)	0.003289 (0.032713)	0.716565* (1.757526)	0.648891*** (6.452220)
Nicaragua	0.882597** (2.330317)	0.567470** (2.260707)	1.009482*** (6.354114)	17.78267*** (3.274904)	0.633132* (2.004968)
Panama	0.633735** (2.165548)	0.740654 (1.341504)	0.290437** (2.107146)	1.582237 (0.990961)	0.261600 (1.002869)
Paraguay	0.307197** (3.939158)	0.006614 (0.590272)	0.572019*** (6.894238)	0.187100 (0.999023)	−0.050581 (−0.967418)
Peru	0.328834** (2.884144)	0.114678* (1.813028)	0.360417*** (5.283010)	0.165805 (0.810518)	0.238572** (2.187999)
Uruguay	0.026475* (1.817431)	3.339575*** (7.780925)	1.006624*** (13.30137)	0.417230 (0.663512)	0.301146** (2.563983)
Venezuela, RB	1.257827*** (4.669931)	0.394900** (2.615896)	0.428761*** (11.36023)	1.183546*** (3.307435)	0.433738*** (5.435224)
Panel Results	0.370619** (2.627594)	0.4222878** (2.296404)	0.496302*** (4.958974)	1.931303* (1.839365)	0.3610855*** (3.850926)

Figures in the parenthesis ( ) are the *t*-statistics.

** Significance at the 5% level.
*** Significance at the 1% level.

Table 5
The results of the Granger causality.

	Short run causality						Long run causality
	LGDP	LRE	LNRE	LGFC	LL	LTD	ECT(-1)
LGDP	–	4.155904***	2.178924*	5.278937***	0.803622	8.552452***	−2.625260***
LRE	15.68220***	–	−2.414081**	0.142056	2.030717*	2.394706**	−3.664079***
LNRE	0.450628	−4.210954***	–	4.707543***	1.895092	9.619681***	−2.865919**
LGFC	1.499133	0.512172	1.927600	–	0.467369	0.882792	−1.976249*
LL	0.560771	0.694913	6.315006***	6.401437***	–	0.877757	−2.584054**
LTD	5.422911***	1.360415	−0.757620	4.336973***	−0.758029	–	−2.584054**

* Significance at 10% level.
** Significance at 5% level.
*** Significance at 1% level.

non-renewable electricity consumption. However, based on the lagged error correction term ect(−1) a bi-directional long run causal relationship was found between all the variables.

The most important finding in the Granger causality results is that renewable electricity consumption is more significant than the non-renewable electricity consumption in increasing economic growth in the investigated countries. Moreover a negative causal relationship was found between renewable and non-renewable electricity consumption. This indicates that the increase in electricity consumption from renewable sources will reduce the electricity consumption from non-renewable sources and vice versa. In addition, there is an existence of a bi-directional negative causal relationship between electricity consumption from renewable sources and electricity consumption from non-renewable sources. However, the researchers found that renewable electricity consumption has a more significant effect on non-renewable electricity consumption compared to the effect of non-renewable electricity consumption on renewable electricity consumption.

5. Conclusion and discussion

This study investigated the impact of electricity consumption from renewable and non-renewable sources on economic growth in 18 Latin American countries: Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Panama, Paraguay, Peru, Uruguay and Venezuela. To achieve the objective of this study a GDP panel model was constructed taking the period 1980–2010 into account. From the Pedroni cointegration test results, it was found that economic growth, renewable electricity consumption, non-renewable electricity consumption, gross fixed capital formation, total labor force and total trade were cointegrated. In addition, the dynamic OLS (DOLS) results revealed that renewable electricity consumption, non-renewable electricity consumption, gross fixed capital formation, total labor force, and total trade have a long run positive effect on economic growth in the investigated countries. The most important finding of the DOLS results is that renewable electricity consumption is more significant than non-renewable electricity consumption in affecting the economic growth in these countries. The reason behind these results is due to the notion that renewable electricity consumption constitutes more than 50% of the region's total electricity consumption. This statement can be supported by Table 6 (see Appendix A) which shows the percentage electricity sources for the investigated countries. The table reveals that renewable electricity (especially hydroelectric sources) accounts for a large share from the total electricity consumption.

Table 6
The percentage of electricity production sources in the investigated countries.

	1980	1985	1989	1990	1995	1999	2000	2005	2009	2010
Argentina										
ELF	55.724576	41.394013	64.120687	50.208908	49.242707	63.871353	59.890901	59.958669	64.379629	65.691385
ELR	0.2417771	0.2562686	0.2355922	0.210879	0.1745878	0.713327	0.7985603	1.2920534	1.1491236	1.7706745
ELH	38.140331	45.6114	25.667676	35.230587	40.038797	26.584481	32.363064	32.234029	27.777459	26.813185
Bolivia										
ELF	32.365658	34.459459	42.748092	47.555171	56.674395	52.641072	48.479381	58.721405	61.411534	67.109929
ELR	1.9765287	1.2387387	1.5744275	1.384682	1.4905598	1.3398609	1.3917526	1.1642157	1.0782552	0.6501182
ELH	65.657813	64.301802	55.677481	51.060147	41.835045	46.019067	50.128866	40.114379	37.510211	32.239953
Brazil										
ELF	6.2189251	4.5745087	5.2364766	4.4955368	4.9285017	8.6655553	8.6678513	10.230428	8.0987562	12.384305
ELR	1.295729	1.5830072	1.5361836	1.7318834	2.0297459	2.5000299	2.2487174	3.3952555	5.1220831	6.5384123
ELH	92.485346	92.096839	92.401241	92.768635	92.12775	87.536897	87.243988	83.729372	83.874566	78.187391
Chile										
ELF	32.124926	19.764957	39.003986	46.162639	27.594819	61.969263	51.452168	46.116912	51.012812	59.612139
ELR	0.893541	1.3888889	1.802257	5.2416721	6.7042495	2.6308935	2.3479216	3.4239006	7.1687362	4.2674653
ELH	66.981533	78.846154	59.193757	48.595689	65.700931	35.399844	46.19991	50.459188	41.658707	35.93507
Colombia										
ELF	29.022792	30.62959	22.982556	23.61581	23.595374	20.139181	24.475362	19.830343	27.173058	27.914143
ELR	1.1102416	0.995266	0.7835287	0.7536375	1.1166776	1.0672084	1.1501449	1.0966089	1.0474042	0.9473165
ELH	69.866967	68.375144	76.233915	75.630553	75.287948	78.793611	74.374493	79.073048	71.779538	71.138541
Costa Rica										
ELF	4.3126685	1.7755682	2.4046921	2.4798155	16.957862	2.1524519	0.8527244	3.2808717	4.8437332	6.6882304
ELR	0.4492363	0.3551136	0	0	9.9691675	14.711118	16.996676	17.227603	17.559875	17.529215
ELH	95.238095	97.869318	97.595308	97.520185	73.07297	83.13643	82.1506	79.491525	77.596391	75.782554
Cuba										
ELF	89.478426	90.286089	90.419319	87.613152	71.346015	73.226608	65.759713	49.465519	52.047608	52.572283
ELR	9.5505056	9.2712517	8.3995013	9.6445687	5.5381652	6.0792161	6.2799361	2.7375831	3.0403881	2.6843709
ELH	0.9710682	0.4426592	0.5380931	0.6056976	0.5939481	0.710737	0.5920703	0.4432277	0.8517599	0.5575674
Dominican Republic										
ELF	80.570902	71.401198	84.669739	89.886425	88.22348	85.200625	90.630124	80.819883	87.182131	88.252287
ELR	2.3020258	1.1976048	0.7680492	0.6760411	0.748585	0.4820219	0.4450691	0.2871571	0.2405498	0.2327074
ELH	17.127072	27.401198	14.562212	9.4375338	11.027935	14.317353	8.9248067	18.89296	12.57732	11.515006
Ecuador										
ELF	74.139976	28.060553	14.127232	21.452197	38.77091	30.374466	28.298153	44.840481	47.324542	52.669538
ELR	0	0	0	0	0	0	0	0.3978041	2.4248038	2.5216624
ELH	25.860024	71.939447	85.872768	78.547803	61.22909	69.625534	71.701847	54.761715	50.250654	44.8088
El Salvador										
ELF	1.5068493	6.6236811	8.0788177	6.8079351	42.175227	35.803474	41.930708	41.794447	43.707923	34.97076
ELR	33.69863	24.736225	21.724138	18.890893	13.383686	16.232356	23.275096	23.622047	30.312446	30.208855
ELH	64.794521	68.640094	70.197044	74.301172	44.441088	47.964169	34.794196	34.583506	25.979631	34.820384
Guatemala										
ELF	85.348361	61.233211	9.2945663	8.3714547	33.560091	42.986687	48.280423	34.262337	42.205996	33.106884
ELR	2.6639344	4.9450549	11.058151	13.037511	12.613379	11.479838	10.019841	17.169522	30.025445	29.59692
ELH	11.987705	33.821734	79.647283	78.591034	53.826531	45.533475	41.699735	48.568141	27.768558	37.296196
Honduras										
ELF	13.686534	6.4516129	2.3984337	1.7248814	38.673021	37.852779	38.088719	66.355978	55.15873	53.890704
ELR	0	0	0	0	0	0.0290951	0.0273823	2.8499731	2.1520147	2.0641521
ELH	86.313466	93.548387	97.601566	98.275119	61.326979	62.118126	61.883899	30.794049	42.689255	44.045144
Nicaragua										
ELF	47.064677	43.217054	35.471456	38.641043	54.555256	72.622345	78.604849	65.388397	69.099334	62.995354
ELR	1.7910448	31.20155	30.211674	33.699382	23.504043	9.2336103	12.462782	20.419535	22.29945	23.230391
ELH	51.144279	25.581395	34.31687	27.659574	21.940701	18.144044	8.9323692	14.192068	8.6012163	13.774255
Panama										
ELF	45.584989	18.140496	13.643411	14.731304	30.86104	31.135371	29.568242	35.695898	43.592694	43.172934
ELR	1.214128	2.1487603	1.8217054	2.104472	0.4262575	0.6331878	0.4910988	0.3947143	0.3307925	0.2965359
ELH	53.200883	79.710744	84.534884	83.164224	68.712702	68.231441	69.940659	63.909387	56.076514	56.53053
Paraguay										
ELF	8.4745763	0.5624847	0.0164386	0.0257495	0.2651703	0.0288628	0	0	0	0.0018496
ELR	5.6062581	0.9048667	0.0904122	0.0698915	0.0781305	0.0692707	0	0	0	0
ELH	85.919166	98.532649	99.893149	99.904359	99.656699	99.901866	100	100	100	99.99815
Peru										
ELF	29.269265	21.137809	22.401107	23.196698	19.666749	22.930672	18.012454	27.679517	38.929211	42.185628
ELR	0.8473731	1.3954256	1.0563124	0.9849363	0.9167493	0.7352941	0.7984333	1.4196635	1.5123447	2.0424085
ELH	69.883362	77.466766	76.54258	75.818366	79.416501	76.334034	81.189113	70.90082	59.558444	55.771964
Uruguay										
ELF	24.173913	1.9222037	31.242355	5.0510478	6.4531473	22.894078	6.615709	12.496746	31.261983	12.487494
ELR	0.1956522	0.4237929	0.5591473	0.7925846	0.6976375	0.6533222	0.4612546	0.5076803	9.4169392	8.6948613
ELH	75.630435	97.654003	68.198497	94.156368	92.849215	76.452599	92.923036	86.995574	59.321078	78.817644
Venezuela, RB										
ELF	59.257604	52.108268	39.836862	37.656142	29.948534	24.835345	26.251598	26.791605	28.113397	35.135592
ELR	0	0	0	0	0	0	0	0	0	0
ELH	40.742396	47.891732	60.163138	62.343858	70.051466	75.164655	73.748402	73.208395	71.886603	64.864408

Note: ELF denotes electricity production from oil, gas and coal sources (% of total), ELR denotes electricity production from renewable sources, excluding hydroelectric (% of total), and ELH denotes electricity production from hydroelectric sources (% of total).
Source: World Development Indicators (WDI) 2013.

The Granger causality results revealed a bi-directional causal relationship between renewable electricity consumption and economic growth, total trade and economic growth, renewable electricity consumption and non-renewable energy consumption, and total labor force and gross fixed capital formation. In addition, a one way causal relationship was found from non-renewable energy consumption to economic growth, gross fixed capital formation to economic growth, total labor force to renewable electricity consumption, total trade to renewable electricity consumption, gross fixed capital formation to non-renewable electricity consumption and total labor force to non-renewable electricity consumption. Based on the lagged error correction term ect(-1), the most important conclusion in the Granger causality test is that electricity consumption from renewable sources is more effective in increasing the economic growth than the non-renewable electricity consumption in the investigated countries. Moreover, a negative causal effect between renewable and non-renewable electricity consumption was found, however, the magnitude effect revealed that renewable electricity consumption is more significant than the non-renewable electricity consumption. From the results obtained from this study it is recommended that these countries should increase their investment in renewable energy project to increase the role of electricity consumption from renewable sources. In addition, it is essential that the investigated countries should decrease their non-renewable electricity consumption by increasing their energy efficiency and utilizing energy saving projects. By applying these recommendations, these countries would be able to mitigate global warming and reduce their dependence on fossil fuel to increase their energy security.

Appendix A

See Table 6.

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